G.U. Journal of Science
22(4): 301-311 (2009)

GUJS
www.gujs.org

A Field Study on Drivers' Thermal Comfort with Road Trials

Tülin GÜNDÜZ CENGİZ[1♠]

[1] Uludağ University, Faculty of Engineering and Architecture, Department of Industrial Engineering, 16059 Bursa, TURKEY

Received: 17.02.2009 Revised: 22.05.2009 Accepted: 22.05.2009

ABSTRACT

This study demonstrates the effects of thermal comfort in real traffic conditions. An experimental system on road is designed to evaluate drivers' thermal comfort. The aim of this study was to determine the thermal comfort values preferred as "thermo neutral" while they drive on the real traffic conditions. The measurements were performed with ten subjects during one hour driving period. Temperatures at eight points and skin wettedness at two points of human body were measured. In parallel, data were collected from a questionnaire consisting 10 questions. Only "thermo neutral" and "dry" values from data were considered. The study revealed that waist and back area were the most sensitive among the other measuring areas. Weighted average of skin temperature, which has been preferred as thermo neutral, changed between 32.95°C and 35.4°C. It was determined that skin wettedness of 26% on front and 38% on back was most preferred. Industries can use findings to evaluate their ergonomic seat comfort in vehicle and the results of this study can be applied to related industrial applications.

Key Words: *Thermal comfort; driving comfort; road trials.*

1. INTRODUCTION

Meaning of comfort/discomfort or thermo neutral is still under great discussion among scientists. The comfort is associated with a relaxed and less stressful situation where it is not necessary to think or concentrate at the task [1]. Basically, comfort is absence of discomfort.

Thermal comfort has an important aspect to be considered for the ergonomic evaluation of vehicle. According to ISO 7730 [2], thermal comfort is that the condition of mind in which satisfaction is expressed with the thermal environment. It is the range of temperature, humidity, and air velocity on which most of the people would feel comfortable.

Human thermal comfort in automobiles is a complex task. The climate is far from uniform and considerable local thermal effects must be visualized and evaluated [3]. The optimum temperature depends upon the type of work, subjective parameters, and other environmental factors. The optimum comfort temperature for sitting work is often described as being in the range close to 25°C [4]. Increasing peripheral heat loss is present in situations of increasing sleepiness [5]. Daanen et al. [6] have implied that thermoneutral temperature in a car enhanced driving performance and may thus positively affect safety. Drivers are exposed to discomfort from more than one source simultaneously. Drivers' performance are affected the psychological and physiological effects of thermal strain. To drive safely, drivers use their ability to perform multiple tasks and take into account many factors such as other road users, car signals and the road environment [7].

The comfort analyses are based on several evaluating methods. These methods can be as theoretical or simulation on computer, in laboratory using human subjects, in a laboratory using a thermal manikin, or on the road with participants. According to Rosendahl and Olesen [8], using thermal manikins are not always directly comparable due to difference between the various manikin types. Besides, driving performance in real traffic has more realistic than the simulator tests; this seemed to be related to poor motivation during the simulator tests [9]. Cengiz and Babalık [10] suggested that the effects of real traffic conditions must be accounted for in comfort predictions.

It is important to determine the subjective judgmental words for the thermal comfort and relate them to the objective measurement. The subjective evaluation of

♠Corresponding author, e-mail: tg@uludag.edu.tr

discomfort may influence their opinions about the vehicle. Design targets (i.e., human criteria for objective data) cannot be established without considering perceptions of comfort [11]. Nishimatsu et al. [12] have investigated the relationship between seat cover material and thermal comfort using subjective and objective measurements in human subjects. Heat sensation associated with thermal comfort most clearly identified by human subjects and measurement of total sweat exuded is a useful tool in work of thermal comfort [13]. Brooks and Parsons [14] have presented the thermal comfort as skin temperature, seat surface temperature and subjective measurements with human subjects. Fanger [15] have conducted an original comfort chamber research at 50% relative humidity and 0.1m/s air velocity, with 1300 people being sat in a climatic chamber. In the study, the participants were asked the temperature in which they feel comfortable. According to results of this study, the maximum 60% of the people would be satisfied (at 24°C) and the rest 40%, however, felt themselves cool or warm.

How the drivers feel themselves is important issue since this feeling is a result of the all effects of the comfort in the car. The results of the objective measurements are really important while the drivers feel themselves ideal or thermo neutral. The aim of the present study was to assess the influence of the driver's preferences on thermal comfort while driving.

2. THE EXPERIMENTAL STUDY

The experimental study was designed for summer driving conditions. All experiments have been performed on sunny days at the same time of the day, at 11:00 AM and 02:00 PM considering the variability of thermal conditions both in the car and outside. 100% polyester seat cover materials have been used since it is the most common used fibre in car seat.

2.1. Participants and Clothing

Ten healthy and volunteer Turkish drivers (seven male and three female) were selected to include a wide range of body sizes (Table 1). The body mass indexes (BMI) of participants were between 19.87 and 27.05. They had fulfilled the following criteria: Resident in Bursa municipality; possess of a valid driving license for at least 5 years. The participants drive average 4–5 day a week, mainly on city roads. They were given brief explanation about the general purpose of the experiment, subjective questionnaires and traffic conditions, and instructed on how to use the seat and auto etc., before they have begun their experiment.

Table 1. The characteristics of participants.

10 participants: 7 male, 3 female			
	Mean	Min.	Max.
Age	31.8	30	34
Height [cm]	174.77	155	189
Weight [kg]	70.13	51	87
Body mass index [kg/m^2]	22.95	19.87	27.05
Driving experience	7	5	12

Clothing was provided for the participants during the trials except underwear, socks and shoes. Provided clothes were consisted of a white colour shirt and trousers. The approximate insulation value of the entire clothing ensemble was 1.5 clo according to ISO 9920 [16].

2.2. Objective Measurements

Ten locations were chosen to measure on human body. Eight sensors for skin temperature and two sensors for skin wettedness were placed to the locations, as seen in Table 2. Here, "objective" was represented as "o".

Table 2. Objective measurement points on the body.

Parameter	Measurement area	Unit
T1o, Temperature	Under thigh	°C
T2o	Inter thighs	°C
T3o	Stomach	°C
T4o	Side of body	°C
T5o	Chest	°C
T6o	Waist	°C
T7o	Back	°C
T8o	Right bottom	°C
SW1o, Skin wetness	Torso front	%
SW2o	Torso back	%

Skin temperatures and skin wettedness were recorded with ergo-physiological equipment, PAR-Port. All data were recorded in a trial information file with a sampling rate of 0.1 seconds. PAR-Port records the temperature in the range of 10-50°C on 0.02°C of sensivity and skin wettedness in the range of 1-100% on 1% of sensivity. The sensors were fixed on skin surface with a band, which has holes. A temperature sensor is 0.5 cm^2 and a skin wettedness sensor is 1.2 cm^2 as seen in Fig. 1. In this way, air circulation was obtained on the skin surface so that the drivers were not influenced from these sensors.

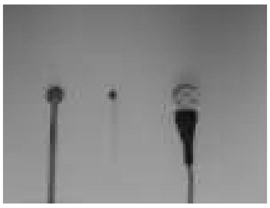

Figure 1. Temperature and skin wetteddness sensors.

The inside temperature and humidity of the trial auto and ambient temperature were also recorded during the trial by supervisor at every 5 minutes.

2.3. Subjective Measurements

Participants were required to complete a questionnaire at the start of each session and every 5 minutes intervals and the answers were recorded at the same time. The questionnaire consists of two parts including thermal sensation on 8 different areas and body moisture on 2 areas. An evaluation of the sensation of thermal comfort for the whole human body in steady-state conditions is possible using the PMV (predicted mean vote). The 7-point sensation scale from “cold” to “hot” was similar to the ones presented in ISO 7730 [2]. The body moisture scale was consisted of 4-point from “dry” to “wet”. All the questions and scales are given in Table 3. Here, ‘s’ refers to ‘subjective’.

Table 3. Subjective questionnaire.

No	Subjective parameter	Question			Scale
1	T1s	At this moment,	how do you feel your	under thigh?	1.cold 2.cool 3.slightly cool 4.thermo neutral 5.slightly warm 6.warm 7.hot
2	T2s			inner thighs?	
3	T3s			stomach?	
4	T4s			side of body?	
5	T5s			chest?	
6	T6s			waist?	
7	T7s			back?	
8	T8s			bottom?	
9	SW1s		how do you feel body moisture on your	torso front?	1.dry 2.slightlyhumid 3.humid 4.wet
10	SW2s			torso back?	

2.4. Experimental Procedure and Road

The experiments were carried out at 25°C in the car. The air velocity was between 0.15 and 0.20 m/s depending on climate function. An instrumented Fiat-Marea equipped with automatic climate function was used in the experiments. The constant temperature in the car was obtained using this climate function (SD=±1°C). The air distribution was fixed in the "windows" mode. Consequently, participants were not affected directly from the climate function.

Firstly, participants came to the preparation room and their bodies were cleared away from the sweat. Then, the sensors were fixed on their body and were dressed trial clothes. The participant sat into the trial vehicle and he/she was asked to adjust the seat and steering wheel to the comfortable positions, and the mirrors to facilitate side views and rear view. They were asked to drive normally and to obey normal traffic rules. Each subject started the experiment with 2 km training period. During this period, they drove to become accustomed to the car.

During the experiment, the driver's first task was to drive as usual on a two-lane city ring traffic and local vehicular traffic. The second task was to answer to supervisor when asked. The subjects were accompanied in the car by an experiment supervisor sitting in the back seat.

Each road trial was took 1 hour in different road conditions along 66 km. Participants drove a Fiat Marea on the road consisting of a city and an intercity part. To minimise environmental effects, the experiments were conducted at the same times of the sunny days. This standardization helped to control the effects of extraneous variables, which could influence subjective discomfort data (e.g. previous activity, road traffic, fatigue, weather conditions, etc.). The test route was composed between Bursa (a city at northwest of Turkey) and Mudanya (a district near Bursa). After completing the experiment, the participants put off trial clothes and all sensors from their body. This procedure was randomly repeated three times for each subject. A total of 30 trials were performed. Ten participants drove three times during the 30 experimental sessions

3. RESULTS AND DISCUSSION

Data were analyzed with SPSS. Firstly, the objective data were re-arranged that the data fitted by subjective results were only "thermo neutral" responses for temperatures and only "dry" responses for skin wettedness. In other words, only "ideal" responses were selected, the other results were neglected. Objective results were taken into consideration, which only corresponded to "ideal" responses. By this approach, it can be detected the objective values stated subjectively ideal by drivers during experiments.

The normality assumption was evaluated by pooling all data for each dimension, separately for subjective and objective measurements, and performing the Kolmogorov–Smirnov test. The results indicated that 7 of the 10 dimensions were normally distributed: T1o, T2o, T4o, T5o, T6o, T7o, T8o ($p>0.05$). T3o, SW1o and SW2o were not normally distributed ($p<0.05$).

One sample T test was used to check mean value against mean of population. Test results showed that T1o, T2o, T4o, T5o, T6o, T7o and T8o had statistically significant difference for "thermo neutral" responses ($p<0.001$).

Table 4 shows all statistics of the data, consisted of "thermo neutral" / "dry" responses. In other words, these data were collected on which the participants reported "thermo neutral" / "dry". They reported at the most "thermo neutral" on the side of body (237 times) and "dry" on the torso front (224 times). However, the numbers of "thermo neutral" on the waist and backareas were lowest. The highest temperature measured on the target locations of the body was on the waist (36.8°C in peak data and also in mean data) and the lowest was on the bottom (32.95°C).

Table 4. The statistics for recorded “thermo neutral / dry” data.

Parameter	The number of thermo neutral or dry response	Value of the most preferred comfortable	Weighted average	Std.Dev
T1	141	34.20 °C	34.43 °C	1.31
T2	211	33.60 °C	33.29 °C	1.34
T3	206	34.60 °C	34.42 °C	1.17
T4	237	33.60 °C	34.51 °C	1.09
T5	220	33.60 °C	34.00 °C	1.10
T6	88	36.80 °C	35.31 °C	1.07
T7	76	35.00 /36.20 °C	35.54 °C	1.03
T8	92	33.60 °C	32.95 °C	1.75
SW1	224	26 %	38.36 %	14.83
SW2	137	38 %	42.65 %	18.94

The Figures 2-11 show distribution of skin temperature, which measured on people who preferred themselves comfortable. As seen in Figure 2, the temperature range of under thigh (T1) was between 30.60°C and 37.20°C. The participants defined at the most 34.20°C (12 times) and there was a contact between driver body and seat cushion on this area. Here, the normal distribution curve was parallel with Fangers’ (1970) study. On the inner thighs area (T2), the temperature range was between 30.60°C and 36.40°C. The participants defined at the most 33.60°C (24 times), as shown in Figure 3.

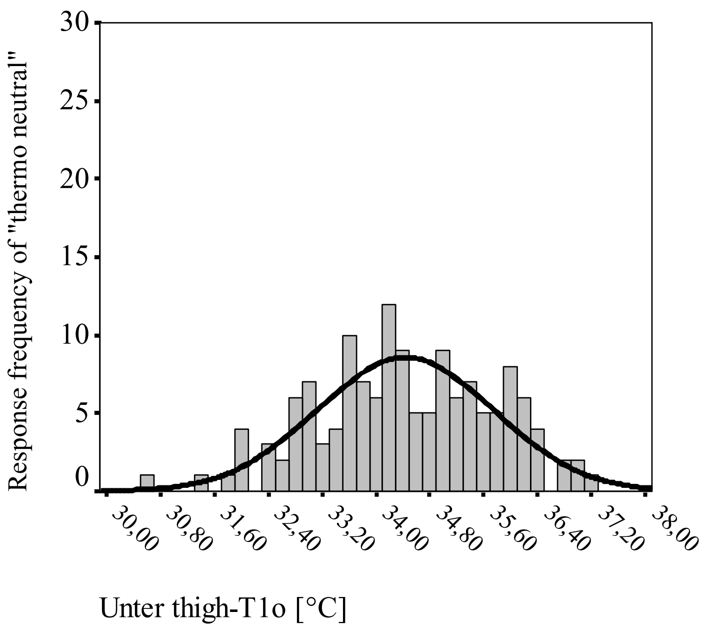

Figure 2. The distribution of skin temperature on under thigh (T1o) on which people preferred themselves comfortable as “thermo neutral”.

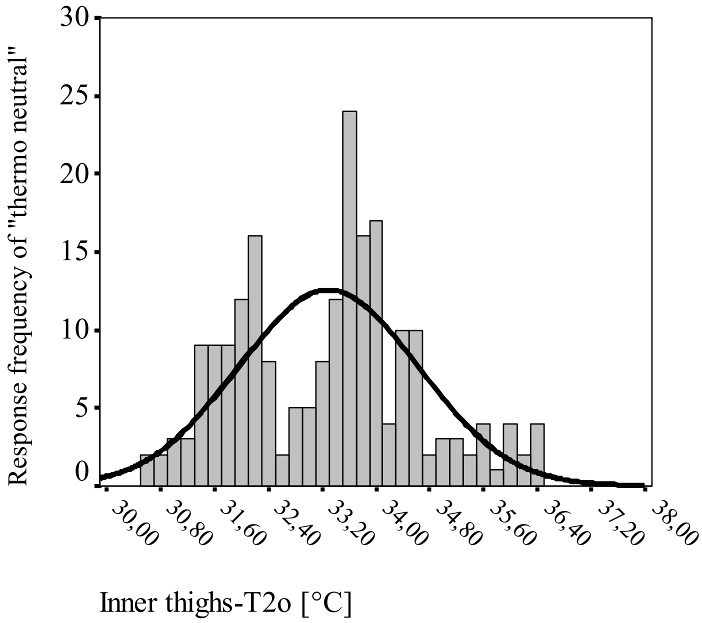

Figure 3. The distribution of skin temperature on inner thighs (T2o) on which people preferred themselves comfortable as "thermo neutral".

The range of temperature was between 31.20°C and 36.80°C on the stomach area (T3) (Figure 4). The participants defined at the most 34.60°C (25 times), and 34.40°C (22 times). Since there was no contact between drivers body and seat material on these areas, "thermo neutral" response was more frequently given by drivers than the other areas, which have a contact between participants' body and seat. As seen in Figure 5, on the side of body two peak values were recorded; at 33.60°C (25 times) and at 35.00°C (22 times).

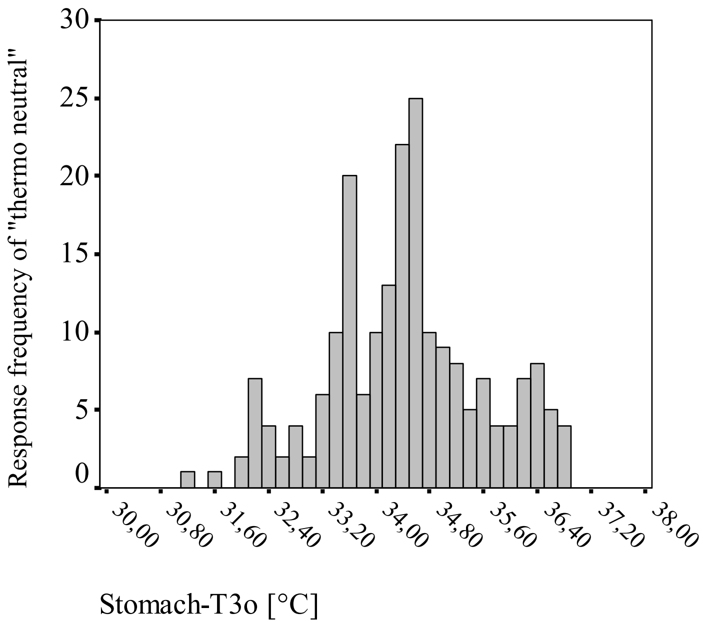

Figure 4. The distribution of skin temperature on stomach (T3o) on which people preferred themselves comfortable as "thermo neutral".

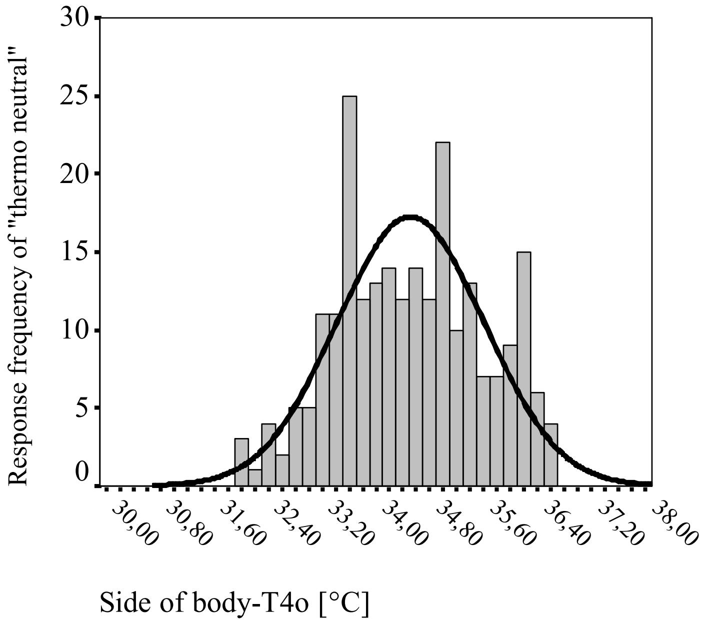

Figure 5. The distribution of skin temperature on side of body (T4o) on which people preferred themselves comfortable as "thermo neutral".

It can be seen from Figure 6 that drivers reported "thermo neutral" at 30 times for the chest area at 33.60°C. The values were between 31.20°C and 36.60°C on this area.

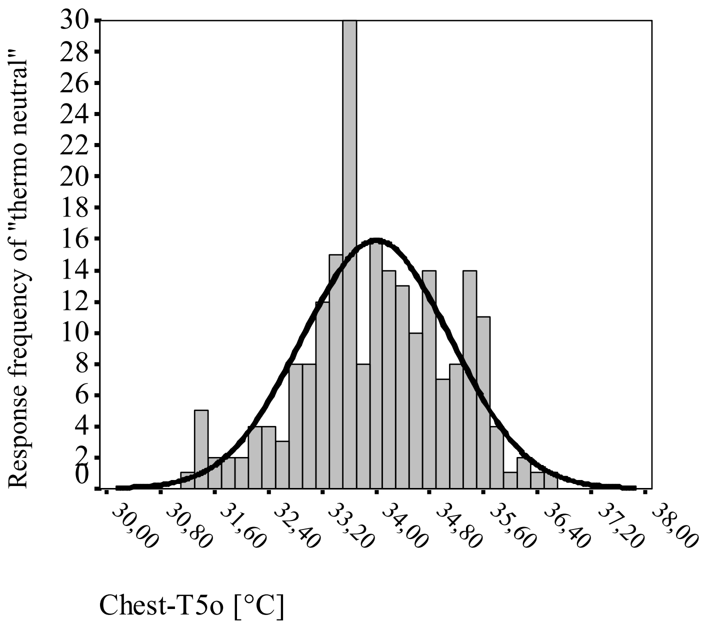

Figure 6. The distribution of skin temperature on chest (T5o) on which people preferred themselves comfortable as "thermo neutral".

The response frequency of "thermo neutral" on waist and back area was few as seen in Figures 7 and 8. The waist area is appeared the most sensitive area on the driver' body. On these areas, the participants reported few times as "thermo neutral" when compared to other areas. The 36.80°C was defined as "thermo neutral" by drivers (10 times) and this temperature was around kern temperature of the body. The temperature range defined as "thermo neutral" on waist and back area was within more narrow range than the other regions. Any clear peak value was not seen on the back area (Figure 8), since the drivers recumbent their back occasionally while they driving but sometimes they remove their back from the seat. An air current occurred between the drivers' body and the seat back is a consequence of this behaviour. In the experiments, any clear peak was not occurred probably due to the air current in the interface.

As seen in Figure 9, the normal curve was left aligned for the bottom area and the participants reported maximum 10 times as "thermo neutral" at 33.60°C. Since there was a strong contact between the drivers' body and the seat cushion on this area, and the drivers felt uncomfortable.

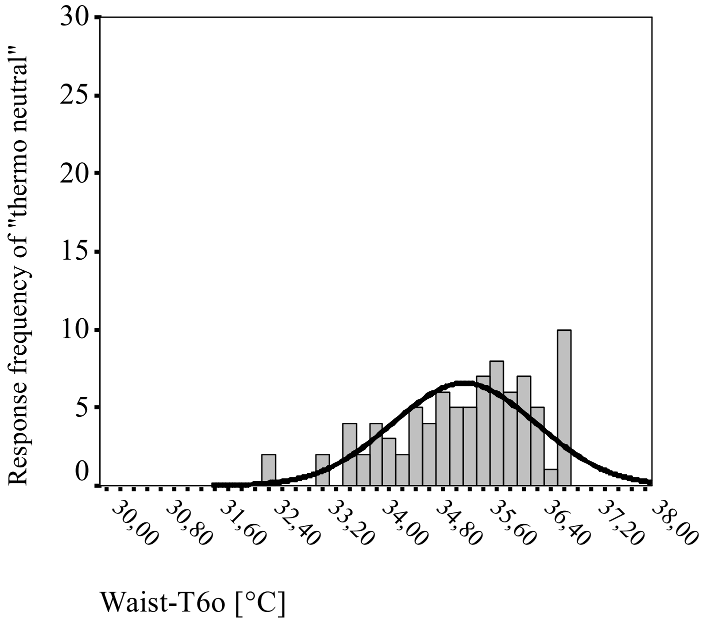

Figure 7. The distribution of skin temperature on waist (T5o) on which people preferred themselves comfortable as "thermo neutral".

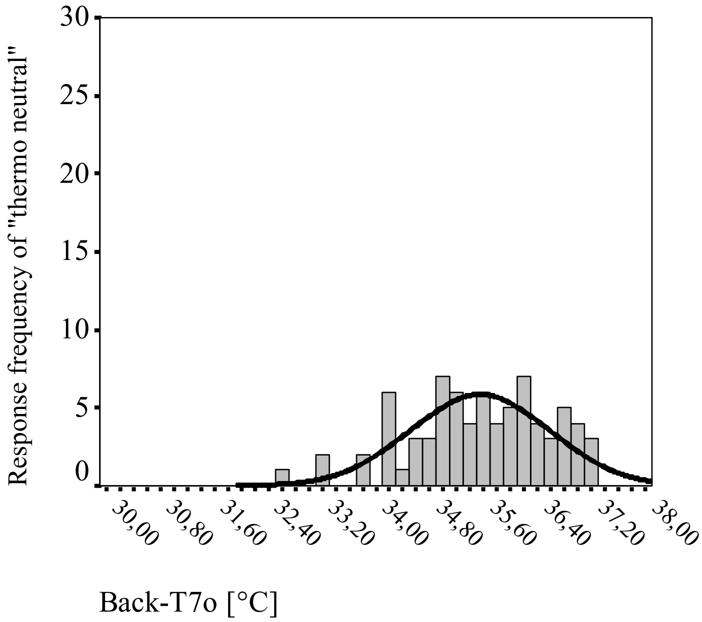

Figure 8. The distribution of skin temperature on back (T6o) on which people preferred themselves comfortable as "thermo neutral".

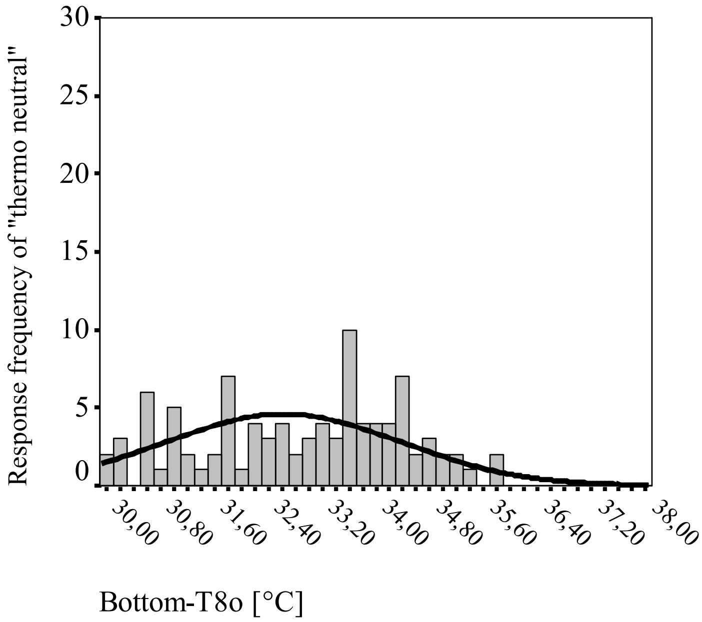

Figure 9. The distribution of skin temperature on bottom (T8o) on which people preferred themselves comfortable as "thermo neutral".

Figure 10 and 11 shows the skin wettedness on front and back of the body where drivers reported as "dry". It was determined that skin wettedness on back was higher than on front, because the back of the body was rested to seat back. Skin wettedness of 26% and 38% were the most preferred for front and back parts of body, respectively. The front of body is open to air current but the back of body is rested most of time, which means this area is close to air current.

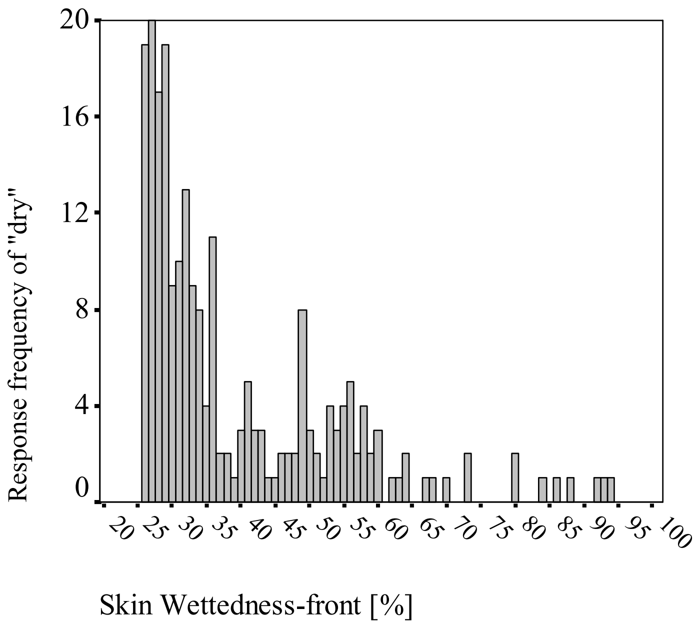

Figure 10. The distribution of skin wettedness on torso front (SW1o) on which people preferred themselves comfortable as "dry".

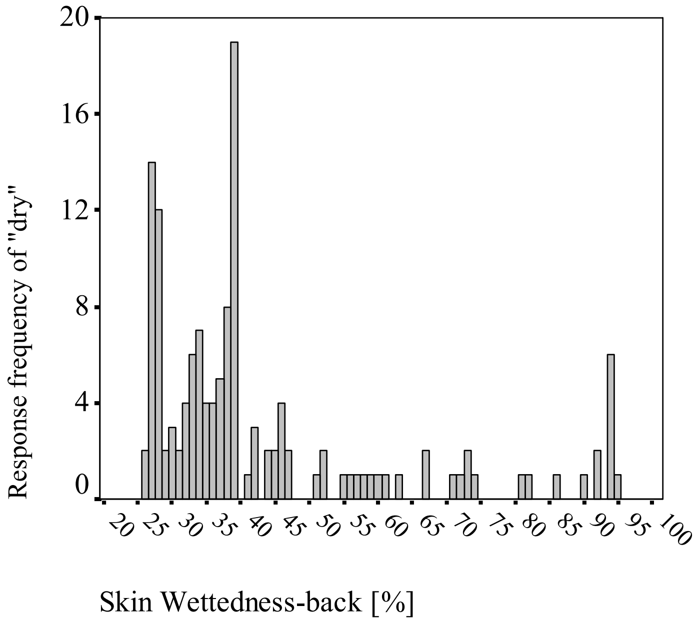

Figure 11. The distribution of skin wettedness on torso back (SW2o) on which people preferred themselves comfortable as "dry".

It can be concluded that the measured data are changeable on which the participants preferred as "thermo neutral" and "dry". That difference was up to 6.5°C from time to time. For instance, the participants evaluated as "thermo neutral" at both 30.6°C and 37.2°C on under thigh (T1). The similar differences were seen for the other areas. Consequently, there is no a constant temperature value on which all/most of drivers defined as "thermo neutral", as Fanger [15] determined. It is well known thermal conditions cause temperature variation across the body [17]. The human body involves complex dynamic system, the properties of which vary from moment to moment and from one individual to another.

In order to improve driving comfort for drivers, it is necessary to understand that how they feel themselves for thermal comfort. The drivers characterized different temperature values as "thermo neutral" for different area on their body. From Table 4, it is seen that weighted average of skin temperature were between 32.95°C and 35.54°C for different measuring areas on the body. These results were consistent with the previous studies, which indicated that maximal thermal comfort was associated with a mean skin temperature of around 33.5°C. [6, 18, 19]. The percentage local heat discomfort was particularly higher in around of back area [20]. The waist and back areas are sensitive areas determining the perception of thermal comfort. The results of this study were in agreement with the previous studies [20, 21], which reported that thermal comfort was mainly affected by local thermal sensation on under thigh, back and buttocks.

Drivers' climate perception for car seats depends upon skin surface temperature and also skin wettedness [22]. According to results of this study, comfortable skin wettedness was between %25-%40 predominantly.

4. CONCLUSIONS

The aim of this study was to evaluate thermal comfort preference of drivers with road trials. The temperatures were measured at eight points and skin wettedness at two points on human body during one hour experiment. Thermal comfort data for each driver were directly measured and this data were used to determine how drivers are influenced by real traffic conditions. The data was also collected from a questionnaire of 10 questions in every five minutes. From all the measurements and subjective evaluations, the temperatures and the skin wettedness were determined for subjective evaluation of "thermo neutral" and "dry".

The average temperature of the waist and the back areas was the highest of the average temperatures. In parallel, the frequency of the thermo neutral responses given for waist and back region was the lowest. It is concluded that the frequency of "thermo neutral" response, on which drivers had no contact with seat material, was higher than the number of "thermo neutral" response on which drivers had a contact with seat material. It was seen that the skin wettedness on the back was higher than the skin wettedness on front. It was determined that skin wettedness of 26% on front of the body and skin wettedness of 38% on back of the body were the most defined as thermo neutral. The weighted average of skin temperature was between 32.95°C and 35.54°C for different measuring areas on the body.

It must be especially emphasized that it is difficult to suggest specific temperature about thermal comfort problem for the people and it is suggested that real traffic conditions must be considered for thermal comfort prediction.

ACKLOWLEDGEMENTS

This work has been carried out with the support of the Uludag University Research Foundation. The authors acknowledge technical support for this project from the auto factory of Fiat-Tofas.

REFERENCES

1. Zhang, L., Helander, M., Drury, G., "Identifying factors of comfort and discomfort in sitting", ***Human Factors***, 38(3): 377–389 (1996).

2. ISO 7730, "Moderate thermal environments–determination of the PMV and PPD indices and specification of the conditions for thermal comfort", (Geneva: (International Standards Organisation) (1994).

3. Nilsson, H.O., "Local evaluation of thermal comfort", ***International Journal of Vehicle Design***, 42(1/2): 8-21 (2006).

4. Landström U., "The effects of climate on wakefulness and fatigue", ***International Journal of Vehicle Design***, 42(1/2): 2-7 (2006).

5. Quanten, S., Valck, E.D., Cluydts, R., Berckmans, D., "Thermoregulatory changes at driver sleepiness", ***International Journal of Vehicle Design,*** 42(1/2): 87-100 (2006).

6. Daanen, H.N.M., Vliert, E., Huang, X., "Driving performance in cold, warm, and thermoneutral environments", ***Applied Ergonomics***, 34: 597-602 (2003).

7. Dukic, T., Hanson, L., Falkmer, T., "Effect of drivers' age and push button locations on visual time off road, steering wheel deviation and safety perception", ***Ergonomics***, 49(1): 78–92 (2006).

8. Rosendahl, J., Olesen, B.W., "Comparison of temperature measurement methods for evaluation of the thermal environment in vehicles", ***International Journal of Vehicle Design***, 42(1/2): 22-34 (2006).

9. Valck, D.V., Quanten, S., Cluydts, R., Berckmans, D., "Day versus night driving in real traffic and on a driving simulator during an 800km all-highway drive", ***International Journal of Vehicle Design***, 42(1/2): 119-133 (2006).

10. Cengiz, T.G., Babalık, F.C., "An on-the-road experiment into the thermal comfort of car seats", ***Applied Ergonomics***, 38(3): 337-347 (2007).

11. Kolich, M., White, P.L., "Reliability and validity of a long term survey for automobile seat comfort", ***Journal of Vehicle Design***, 34(2): 158-167 (2004).

12. Nishimatsu, T., Hayakawa, H., Shimizu, Y., Toba, E., "Influence of top coated cloth for sitting comfort of car driver's seat", ***IEEE Instrumentation and Measurement Technology Conference***, USA, 915–919 (2000).

13. Fung, W., Parsons, K.C., "Some investigations into the relationship between car seat cover materials and thermal comfort using human subjects", ***Proceedings of the 3rd International Conference on Vehicle Comfort and Ergonomics***, Italy, 461-480 (1995).

14. Brooks, J.E., Parsons, K.C., "An ergonomic investigation into human thermal comfort using an automobile seat heated with encapsulated carbonized fabric", ***Ergonomics***, 42(5): 661-673 (1999).

15. Fanger, P.O., "Thermal Comfort", ***McGraw Hill***, Danish Technical Press, Copenhagen, (1970).

16. ISO 9920, "Ergonomics of the thermal environment - Estimation of the thermal insulation and evaporative resistance of a clothing ensemble", (Geneva: International Standarts Organisation), (1995).

17. Landau, K., Stübler, E., "Die Arbeit im Dienstleistungsbetrieb", Eugen Ulmer Verlag, Germany, (1992).

18. Arens, E., Zhang H., Huizenga C., "Partial- and whole-body thermal sensation and comfort—Part II: Non-uniform environmental conditions", ***Journal of Thermal Biology***, 31: 60–66 (2006).

19. Pellerin, N., Deschuyteneer, A., Candas, V., "Local thermal unpleasantness and discomfort prediction in the vicinity of thermoneutrality", ***European Journal of Applied Physiology***, 92: 717–720 (2004).

20. Sakoi, T., Tsuzuki, K., Kato, S., Ooka, R., Song, D., Zhu, S., "Thermal comfort, skin temperature distribution, and sensible heat loss distribution in the sitting posture in various asymmetric radiant fields", ***Building and Environment***, 42(12): 3984-3999 (2007).

21. Cheong, K.W.D., Yu, W.J., Sekhar, S.C., Tham, K.W., Kosonen, R., "Local thermal sensation and comfort study in a field environment chamber served by displacement ventilation system in the tropics", ***Building and Environment***, 42: 525–533 (2007).

22. Paul, G., Ackert, H., "A contribution to the thermo-physiologic assessment of climate seats in passenger vehicles", ***Proceedings of the Annual Spring Conference of the Gfa*** (Gesellschaft für Arbeitswissenschaft), Germany, 123–126 (2003).